# Turbulent magnetic field amplification and supermassive black hole formation the early Universe

## Turbulent small scale magnetic fields in the early Universe

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### In Short

- Structure formation in the early Universe
- Origin of supermassive black holes
- Turbulence and magnetic field amplification
- Accretion disks

The goal of this proposal is to investigate the impact of strongly amplified small scale magnetic fields on the formation of the first stars and seeds of supermassive black holes forming in the early Universe a few hundred million years after the Big Bang [1]. Particularly, we will explore the role of such magnetic fields on the stability of an accretion disk forming as a consequence of gravitational collapse and its implications for the formation of a central object (proto-star).

Owing to the extremely large range of scales (many orders of magnitude), it is impossible to fully resolve dynamical processes such as turbulent fragmentation and magnetic field amplification in cosmological simulations. To address specifically this problem, so-called the subgrid scale (SGS) models are applied to account for the interaction between scales below the grid resolution and the larger, numerically resolved scales in a smulation [2]. However, so far this approach has only been applied in simulations of hydrodynamical flows without magnetic fields. Nevertheless, it was demonstrated that SGS turbulence influences the fragmentation in so-called atomically cooled primordial halos, which are thought to be the birthplace of massive black holes/first galaxies, and the formation of a self-gravitating accretion disk [3]. It is also known that magnetic fields in massive primordial halos are efficiently amplified from small scales via the turbulent dynamo effect. Simulations showed that strongly amplified magnetic fields seem to suppress the fragmentation of the cooling gas [4]. However, the effect of small-scale magnetic fields was resolution-limited in these simulation.

To properly account for the dynamics of turbulence and magnetic fields on sub-resolution scales, we we will for the first time employ the magnetohydrodynamical SGS model [5] to explore the role of unresolved turbulence and magnetic fields during the formation of proto-stars in self-gravitating disks. Our goal is to assess the impact of magnetic fields on the stability of accretion disks, their fragmentation, and the mass scales of the central objects, which are potential seeds of supermassive black holes.

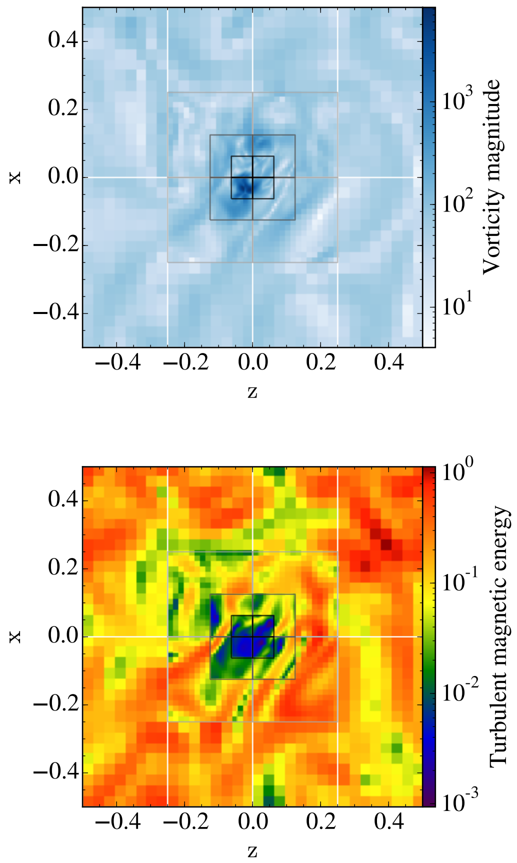


***Figure 1:*** *Slices of vorticity magnitude and subgrid-scale turbulent magnetic energy in a turbulence simulation. The simulation uses three additional nested grid levels (indicated by different shades of grey) in the central area, with 2, 4, and 8 times the resolution of the coarse grid covering the whole box.*

As a proof of concept, we performed simple simulations of magnetohydrodynamical turbulence driven by an external force field in a box with periodic boundary conditions. In order to illustrate the role of the SGS model, slices through the box are shown in figure 1. Similar to cosmological adaptive mesh refinement simulations, we used nested grids with increasing resolution in the central region of the box. It can be seen that the vorticity magnitude, as a proxy for resolved turbulence strength, increases with resolution (i.e. towards the center of the box), while the turbulent magnetic energy on subgrid scales

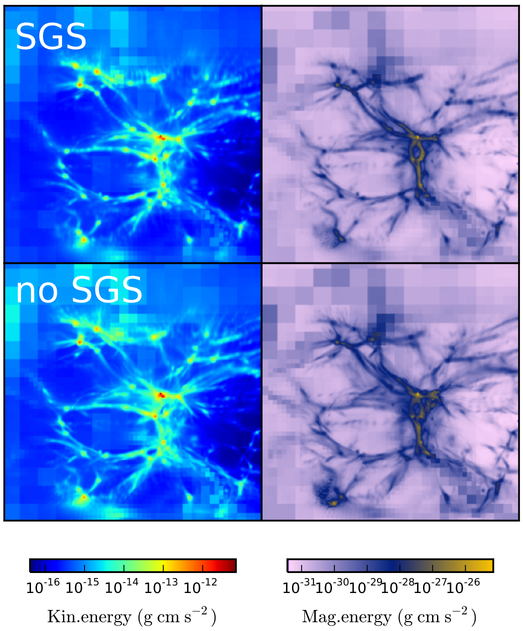


***Figure 2:*** *Kinetic and magnetic energy projections of the central 30 kpc region of the most massive halo in a test run.*

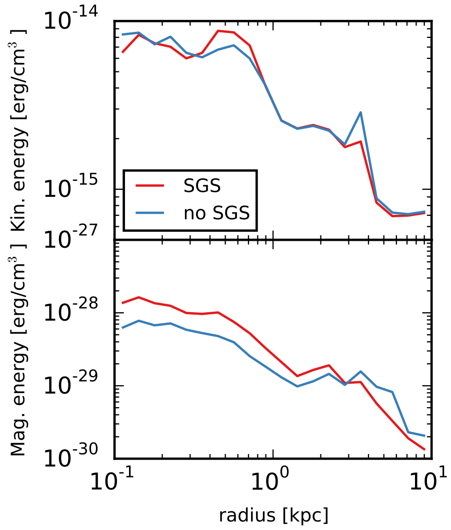


***Figure 3:*** *Radial profiles of kinetic and magnetic energy within the most massive halo of the test runs shown in figure 2.*

decreases with increasing resolution. This is the expected behavior.

Moreover, we have already conducted first low-resolution test runs of cosmological structure formation with and without SGS model. Figure 2 shows the resulting kinetic and magnetic energy densities within the most massive halo approximately 500 million years after the Big Bang. This was mainly intended to check the stability of the numerical implemenentation of the SGS model. The effects introduced by the model are marginal because only very little turbulent substructure is resolved in the halo. However, this is necessary for the SGS model to work properly. Nevertheless, we see already first indications of additional magnetic field amplification if the SGS model is added. This can be seen in figure 3, which compares the radial profiles of kinetic and magnetic energy densities in the central region. While there is only very little difference in the kinetic energies, the magnetic energy in the SGS run is significantly enhanced near the center.

To systematically investigate the impact of SGS tubulence on magnetic field amplification and the formation of supermassive black hole seeds, much higher resolutions are necessary. This will be achieved with zoom-in simulations using up to 27 levels of adaptive mesh refinement in addition to nested grids [1,4]. To perform this kind of simulations, HPC facilities with powerful compute nodes with large memory, such as the HLRN-III Cray XC40 system, are required.

## WWW

http://www.hs.uni-hamburg.de/

## More Information


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